1.0 Abstract

International and “European product liability regulations” for process plants requires owners to manage the process plant manufacturing and operation life cycle condition. These authorities require owners to provide evidence of the information provided by contractors, manufacturing records and condition monitoring of their process plants. The responsibility requires traceable records, knowledge management of key people who were responsible during the various phases irrespective of the human resources retirement and are no longer the part of the company. Risk associated can now be minimised by complete transfer of that information into online electronic permanent archives.

Underwater advanced digital radiography inspection technology is being developed which can inspect risers which are laid to the sub-sea depths of up to 3 Km. This acquisition which can be deployed from FPSO by ROV or other methods enables acquisition of digital gamma radiographic images, which are analysed by the inspectors and results are then archived. Once this information is acquired, archived and managed, this serves as the important safety assessment tool for preventative maintenance planning and base for accident avoidance strategy. Latest advancements in digital information technology is that it now utilizes a visual graphically driven methodology that is multi-user, multi-dimensional, hierarchical tree structure information archival and retrieval process. The data source can be from digitized radiography films, digital radiographic images, UT data, manufacturing, inspections, and maintenance records. NDE information includes images, reports, engineering details, technique details and RBI linked safety grading, material, personnel and equipments related to the product and project. This total evidence & trend based information creates large data volume file which is accessible, on-line/on-stream for the duration of the product life cycle (up-to 50 years) offering a significant savings on time and resources. The QA/QC managers and the product/plant owners can have instant access to this NDE data bank of correlated inspection results of historical tests and the current inspections. This would enable them to put the preventative measures and schedule the predictive maintenance of risers and product. This would not only prevent the disasters that could cost millions of dollars but would also increase the safety of the FPSO operations, quality of the product leading to the confidence with the compliances to the regulation and the goodwill of the products and services.

2.0 Introduction

Major oil companies are developing an ever-increasing number of offshore oilfields in their quest to maintain stable world oil and gas supplies. Floating Production Storage and Offloading (FPSO) vessels are being used year round, on station producing oil and gas from deep-water oil fields. Currently, there are in UK 30 FPSOs with about 900 flexirisers and about 180 FPSOs with about 6000 flexible risers deployed offshore worldwide. The number is going to increase to 10 folds in next decade. These consist of different kinds, ranging from fixed platforms to floating ones.
Below is a brief description of different types of oil platforms:

**Fixed Platforms (FP):** These are built on concrete and steel legs that are anchored directly onto the seabed. These support a deck with space for drilling rigs, production facilities and crew quarters. These platforms, as the name implies, are immobile and therefore have long life.

**Compliant Towers (CT):** They are built of slender flexible towers along with a pile foundation, which supports a conventional deck for drilling and production operations. These towers are designed to sustain significant lateral deflections and forces.

**Floating Production Systems (FPS):** They are large mono-hull structures, usually shaped like a ship and equipped with processing facilities. They are moored to a location for long periods and mainly act as storage vehicles.

**Tension Leg Platform (TLP):** These platforms are fixed to the seabed in a way that eliminates vertical movement. A typical TLP has a 4-columned structure and is low in cost.

**Subsea System (SS):** This type of platform has hulls of sufficient buoyancy to make them float, at the same time, having sufficient weight to keep the structure upright. These platforms are quite flexible in terms of that they can be moved from place to place and altered in height.

**SPAR Platform (SP):** SPARs are like TLPs, however, they differ in the sense that they are tethered using catenary mooring lines instead of vertical tension tethers. SPARs are made using three configurations – the conventional one-piece cylindrical hull, the truss spar, and the cell spar. SPAR is much more stable in water due to counter-weight as its bottom and has the ability to move horizontally with the help of mooring lines.

It is estimated that 30,000 tons of oil is leaked or spilled into the world's oceans annually from a total production of around 2.5 billion tons of oil worldwide each year. Therefore, a flexible riser failure is catastrophic leading to high economic and environmental losses. The economic impact can be on the producer liabilities and consequential losses incurred.

Therefore prevention and minimization of these losses becomes the highest paramount priority to tackle these major uncertain situations by the end owners. A corporate governess policy has to be put into place for operation life cycle management to Harness this uncertain situations, the product liability requirements and to minimize risks by associating to the international compliance.
This paper introduces a promising approach how NDT digital radiography can be conducted for inspection of risers.

### 2.1 Current Inspection Trends & Their Drawbacks

Inspection of flexirisers has been a major concern for the oil and gas companies throughout the world. As, a flexible riser comprises of multiple layers, each overlapping and thus, completely hiding the other, it is very difficult to know a possible failure. The harsh and hostile environmental factors further make it difficult to carry out an inspection. While the main layer of concern is the tensile armour layer, which withstands tension loads, it is equally important to inspect other layers as well. Some of the current inspection methods that exist suffer from some major drawbacks, as mentioned below:

**Visual Inspection:** It only inspects external sheath, which requires to be first cleaned off for marine growth. Divers are required, which proves quite expensive and time consuming. Small holes go undetected.

**Polymer Coupon Sampling with FDEMS:** Although it has gained much acceptance with the introduction of Frequency Dependent Electro-Magnetic Sensing (FEDMS), still the data is unreliable because of its dependency on testing method, retrieval and liquid flow. Besides, it only provides a rough idea about the possible damage to internal sheath; not specifying the exact area of defect.

**Vacuum Testing of Riser Annulus:** This method only detects the annulus for leakage i.e. presence of H$_2$O, CO$_2$, H$_2$S, CH$_4$ etc. In some cases, it can indicate possible defects in external sheath.

**Eddy Current Testing:** Although this method has lately found acceptance in NDT industrial testing, for underwater inspection of risers, it hardly proves useful with significant drawbacks. To start with, it only inspects external sheath, in which case also, it cannot be used for bend stiffener, which is itself a critical location for armour failure. The quality of data depends on outer surface i.e. sheath defects and marine growth. It also proves to be time consuming.

**Ultrasonic Testing:** It has not proven useful for sub-sea inspection of risers, flexirisers and other components because a number of drawbacks. Firstly, the riser surface must be cleaned thoroughly to couple ultrasound uniformly at all points. Process of cleaning results in huge volume of contaminated material that must be disposed off properly. This process itself becomes too costly. Secondly, the rough surface of risers, will impair accurate UT detection, as significant lobe energy would be reflected back into the transducer, resulting in scattering and hence loss of echo. Thirdly, the boundary between the couplant wiper and rough surface quickly poisons the couplant with microscopic air bubbles, which is a serious UT problem. Lastly, UT requires a large number of sensors in order to detect wall thickness and imperfections (both linear and angled).

### 2.2 Digital Radiography As An Alternative

Radiography has long proven its capability in industrial NDT. However, industry is still reluctant to use it because of heavy equipment, chemical processing of radiographic films and problem of storage. But with the advent of flat panels, new radiography detectors and imaging plates by CIT, radiation required to capture an acceptable radiographic image is reduced to around 60%, thereby making the entire equipment portable, reducing the radiation control area to anywhere from 1 to 5 meters. Furthermore, using radiography image as detector, acquires radiographic image directly onto computer monitor, eliminating chemical processing and saving considerable time. The images generated can be stored in electronic archives safely, without
degradation for around 50 years. Therefore, CIT brings digital radiographic technique for inspection of risers and flexirisers, which is developed for sub-sea marine environments.

3.0 CIT’s Underwater NDT Digital Radiography Inspection Technology

Specially designed “Marinised” dedicated equipment is used to conduct examination of in-situ underwater risers

Components consist of:

- “Marinised” inspection rig
- Operation control console command centre on the FPSO or ship
- Floating buoyancy unit with flashing beacons
- Cable with cable junction box
- Underwater radiation source and detector with its manipulation system

Deployment method of inspection rig varies as per depths to be achieved:

- Up-to 150 meters from on-boat crane, which lowers the inspection acquisition module into shallow waters ie splash zone section
- From 150 meters to 600 meters by means of ROV deployed to take the inspection acquisition unit to the depth.
- From 600 meters to 1000 meters by means of ROV deployed to take the inspection acquisition unit to the depth
- From 1000 meters to 3000 meters by using DRIFT 3000 inspection rig for dedicated inspection

The source and the detector are kept some distance apart from the flexirser/riser to account for greater cover area and growth over the riser, respectively.

The robotic crawler unit, which consists of detector, Iridium 192 gamma isotope and the radiation control device goes underwater, grips itself to the flexible risers and positions the detector and the radiation device accurately to acquire images. The detector that is attached to an embedded pc generates the radiographic images, which are then analysed and interpreted through CIT’s software applications

This technology is beneficial, as no cleaning of riser surface is required. This is because gamma radiations can easily penetrate through the entire thickness. Also, the setup is automatically controlled from FPSO or boat, considerable time is saved. It also eliminates the need for divers. Multiple radiographs can be taken at a time, without the need to bring the entire equipment to top surface. The image is directly seen on the monitor in few seconds time.

In terms of safety, it is designed with utmost care as it deals with harmful gamma radiations. This is implemented in the form of Operator’s Control Console Unit, which consists of Isotope safety monitoring and radiography warning (audio-visual alarm systems, radioisotope device safe position and CCTV feedback system).

4.0 Data Acquisition
The process:

- Radiographic Image Acquisition. Multiple images can be stitched together to form on a single radiograph – say up-to 1 meter length of riser
- Information Advanced Analysis, Defect Detection and Archiving of large data sets
- Information Retrieval from Local and Remote Access using:
  - CIT/ DR-radiograph viewer
  - CIT/ Schema Retrieval
Corrosion & Condition Monitoring

- Trend Analysis and RBI over a period of time

Reporting

Predictive and preventative actions

Figure below shows a sample of radiographic image achieved:

Manufacturing defects such as cracks and riser imperfections ought to be detected early

QC issues to be taken care of:

- Careful selection and handling of riser
- Vetting of riser material, quality manufacturing
- Pre and post heat treatment procedures and their monitoring
- Fitting of temporary repairs

Radiographic testing based on Digital Radiography opens the gate for in-situ in-service inspection of the following riser defects:

- External Sheath: Buckling, Kinking, holes or tears
- Trenching and damage to pipe configuration near touchdown zone
- Corrosion fatigue, cracks and fissures
- Internal pressure sheath damage due to high temperature and rising water cut
- End-fitting failures
- Over bending/bend stiffener failure at riser-vessel interface
- Carcass: pitting or cracking, wear or erosion
- Pressure Armour & Tensile Armour Wires: Sulphide Stress Cracking (SCC), Hydrogen Induced Cracking (HIC), corrosion and fatigue
Defect Recognition tool and Advanced Image Analysis utility developed by CIT that assists the QA/QC manager to generate the reports from which important decisions are made. These tools and functionality are:

- Inspection criteria set by the end customers, regulatory bodies, and NDT standards
- Flaw database, acceptance criteria, reference radiographs
- Techniques used to achieve the radiographic images,
- Product details, Material details, Manufacturer’s details, Engineering details
- Personnel conducting the tasks, date and time
- Any Other techniques and equipment used relating to the product and project
- Electronic tools for the measurements of the defects, material thickness, flaw depth, corrosion-condition
- Reports generated with the comments; RBI (risked based inspection)
- All previous inspections and reports with images, drawings, photographs for trend analysis

5.0 Corrosion and Condition Management

Any industry’s major concern is to determine the condition of their production plants. There are several maintenance issues such as whether a production unit is fit for carrying out operations or it has become unsafe for use, where is the damage and to what extent. It may include inspection tasks, RBI and trend analysis. CIT’s Corrosion and Condition Management package is equipped with utilities that allow accurate measurements for wall thickness/material loss using profile and tangential radiography methods and flaw depth assessment using parallax method. In addition, it also provides colour mapping to enable quick distinction between different flaws.

Reports can be generated and saved in permanent archives along with radiograph images.

6.0 NDE Information Archival and Retrieval
Data from inspection is archived in digital storage media such as DVDs, Blu-ray Discs and UDOs. Utilities like DRSAM and ADM are used to take multiple copies and synchronise the data. The data can also be viewed online if required via Internet, throughout the lifetime of the product i.e. up-to 50 years.

Latest advancements in digital technology have enabled the development of visual-based methodology for information retrieval called Schema Retrieval. “Schema” is defined as internal representation of any structure revealing internal information; using either two-dimensional or three dimensional visualisation techniques. It enables one to form information hierarchy, thus, access to the total information of the product much easier. The information may consist of digital radiographic images, schematic drawings of components, inspection reports etc. It provides a multi-user, multi-dimensional, hierarchical tree structure information archival and retrieval method. Figure below shows a window of Schema Retrieval package.

As shown in the figure, one can link the images/photograph of the oil platform and the riser (tree type hierarchical storage) packaged along with the graphical link to images of its other parts and components. Areas can be marked into sections on the basis of inspection priority or any other criteria. The sections can then be associated with further images, say of that component itself, which can then be marked (tagged) and attached to radiograph image of inspected component and its complete NDE data. These can interact with the Risk based inspection data.
Product Information

CIT’s technology provides the total information for safety assessment of your oil platform, asset management and product lifecycle data management.

7.0 Benefits

Digital radiography for inspection and maintenance management has proven to be very cost effective, increasing the operating life of the risers.

- Underwater Advanced Digital Radiography Inspection Technology enables inspection of risers laid to a depth of up to 3kms in water.
- Digital acquisition and analysis saves considerable time and recourses
- Electronic analysis tools provides more accurate measurements, eliminating human errors
- Advanced data storage technology allows information to be available 24 hours on-stream/on-line
- Digital data storage (NDE Data Bank) enables creation of trend-based information to carry out predictive maintenance and preventive measures
- Visual-based graphically driven methodology that is multi-user, multi-dimensional provides hierarchical tree structure information archival and retrieval process
- Timely inspection and preventive measures reduce the risk of failure of risers, thereby preventing leakages and ecological damages that could cost millions of dollars
- Provides legal evidence to protect against product liability regulations
- Reduce health and safety risk and environmental damages
- Improves the inspection quality, increases the product lifecycle, and increases the yields
8.0 Commercial Considerations

FPSO owners can commence this preventative measures by setting up surveys of their assets and moving forward with the deployment of CIT/digital radiography technology as the NDT inspection methodology for their raiser and oil platforms:

1. CIT can offer to carry out survey of customer requirements, which will take around 2-3 weeks, where terms of reference related to inspection and inspection planning & management is done

   - Survey to establish current scope
   - Inspection requirements
   - Manufacturers supplied products
   - Historical and current issues
   - Radiographic inspection equipment setup
   - Acquisition methodology
   - Deployment methods with interface
   - Constraints and limitations
   - Reporting

2. Supply of hardware and software where all information can be accessed and retrieved for riser lifetime cycle management

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